

HIGHLY RELIABLE POSITIVE TEMPERATURE COEFFICIENT OF BREAKDOWN IN 4H-SiC PN JUNCTION RECTIFIERS

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Theoretical appraisals of SiC power devices have suggested that once silicon carbide technology matures sufficiently to overcome some developmental obstacles, SiC may supplant silicon in many high-power electronic applications¹. One behavior crucial to power device reliability that has necessarily been assumed to date is that the breakdown behavior of SiC pn junctions will be similar to silicon-based pn junctions. Silicon pn junction power rectifiers are highly reliable because they exhibit stabilizing properties such as positive temperature coefficient of breakdown voltage, which prevents the formation of damaging high-current filaments at hotspots when system glitches temporarily bias a diode beyond its breakdown voltage.

Unfortunately, experimental 4H- and 6H-SiC pn junction rectifiers reported prior to this work have exhibited negative temperature coefficient of breakdown voltage². Because negative temperature coefficient behavior focuses and intensifies breakdown current at localized junction hotspots forming high-current filaments, such junctions are unlikely to withstand any significant overvoltage glitches without sustaining physical damage. Therefore, it is doubtful that these devices could be reliably incorporated into many kinds of power systems without paying cost penalties of additional overvoltage protection circuitry and/or performance penalties of excessive reverse voltage derating.

This work reports the first clear demonstration of stable and reliable breakdown behavior in 4H-SiC. P⁺n (N_D varied between 2.5×10^{17} to 1.5×10^{18} cm⁻³) 4H-SiC mesa diodes, grown with a high quality epitaxial process³, were fabricated with small enough areas ($< 5 \times 10^{-5}$ cm²) that many devices should be free of dislocation and micropipe defects. Because self-heating can cause rectifier junction temperatures to deviate significantly from ambient temperatures, we did not rely on curve-tracer measurements to ascertain the temperature variation of breakdown voltage. Instead, we recorded the time evolution of device current and voltage as diodes were subjected to breakdown bias pulses (200 ns pulsewidth, ~1 ns risetime) at room temperature ambient. We report here the first 4H-SiC diodes that clearly exhibit the classically stable and reliable silicon-like behavior of positive temperature coefficient of breakdown voltage, in that breakdown current flow through the devices decreased while the voltage across the devices increased as the rectifiers self-heated over the 200 ns breakdown bias pulse. In contrast to previously measured unstable 4H- and 6H-SiC devices which failed catastrophically at pulse amplitudes less than 80% of the dc-ascertained breakdown voltage⁴, these devices were able to withstand input pulse amplitudes in excess of 200% of the dc-measured breakdown voltage without material damage. While we were unable to fail positive temperature coefficient junctions during pulse-testing, peak current densities as high as 50,000 A/cm² were recorded prior to contact metallization failures.

This work demonstrates that robust 4H-SiC power devices with the same (if not better) high breakdown reliability of modern silicon power devices should be achievable after SiC technology maturation greatly reduces material defects such as micropipes, dislocations, and deep levels.

¹M. Bhatnagar and B. J. Baliga, IEEE Trans. Electron Devices, vol. 40, pp. 645-655, 1993.

²A. O. Konstantinov, Springer Proceedings in Physics, vol. 56, Springer-Verlag (Berlin), pp. 213-219, 1992.

³D. J. Larkin, P. G. Neudeck, J. A. Powell, and L. G. Matus, Appl. Phys. Lett., vol. 65, pp. 1659-1661, 1994.

⁴P. G. Neudeck and C. Fazi, to appear in J. Appl. Phys., 15 July 1996.

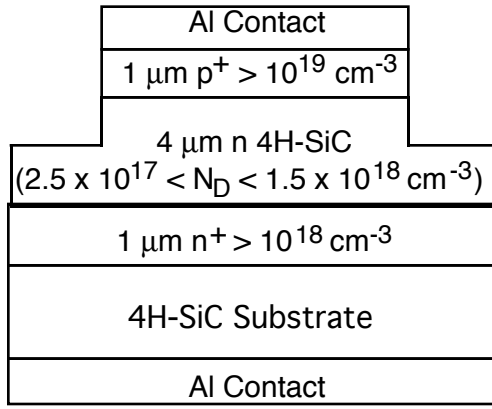


Fig. 1. 4H-SiC pn junction diode cross-section.

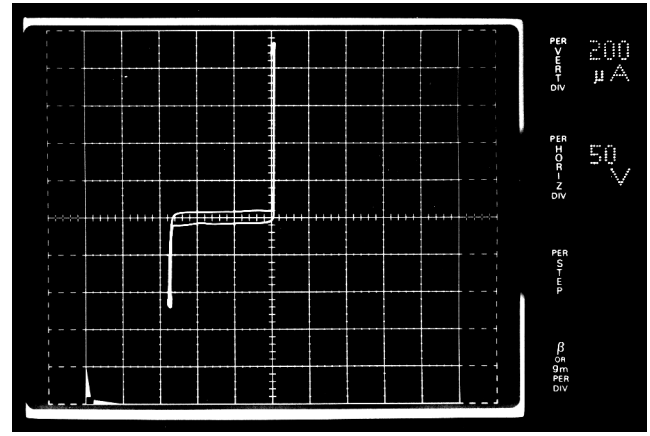


Fig. 2. Curve-tracer measured I-V characteristics of $4.42 \times 10^{-5} \text{ cm}^{-2}$ circular 4H-SiC pn junction rectifier recorded at room-temperature ambient.

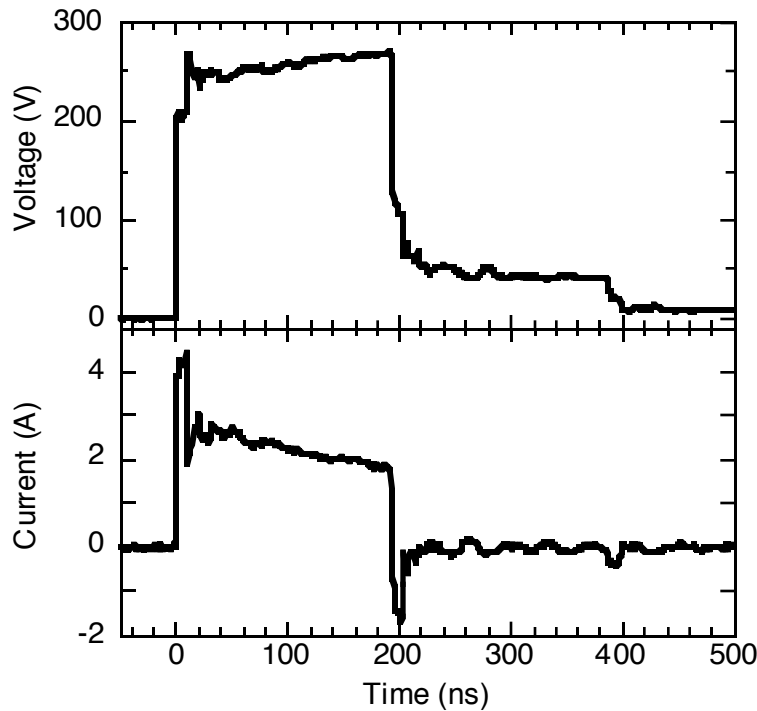


Fig. 3. Room-temperature ambient $V_D(t)$ and $I_D(t)$ data collected on 4H-SiC rectifier (same device as Fig. 2) when subjected to a 200 ns breakdown bias pulse from a charge-line circuit. The diode clearly exhibits the classic silicon-like behavior of positive temperature coefficient of breakdown voltage in that as the device heats up over the 200 ns pulse duration, the breakdown current flow through the device $I_D(t)$ decreases while the voltage across the device $V_D(t)$ increases. The measured voltage across the diode $V_D(t)$ is clamped in the neighborhood of 270 V despite the fact that the input pulse amplitude (which can be measured open circuit when no device under test is present) is 322 V. The current spikes at the rising and falling edges of the pulse are due to displacement current, while the peak conduction current of $\sim 2.5 \text{ A}$ corresponds to a current density in excess of $50,000 \text{ A/cm}^2$.